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# Effect of Stiffeners on Behavior of Steel Plate Shear Wall with Rectangular Openings

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**Abstract.** Steel Plate Shear Walls (SPSWs) with and without stiffeners, due to excellent seismic performance, are considered as a lateral load resisting system. Stiffeners have widely been used in SPSW to improve the buckling behavior of shear panels in steel frames. To attain architectural purpose, adding of rectangular openings in SPSWs is inevitable; therefore, it is essential to investigate on the behavior of SPSWs with rectangular opening. This paper describes the effect of adding stiffeners on the maximum shear load capacity of SPSW with rectangular opening. Specimens with and without stiffeners are modeled and analyzed using Finite Element (FE) method. In the investigated specimens, the variables parameters are thickness, yield strength and opening area of SPSW. Results demonstrated that stiffeners, which are located on surrounding the opening, have more effect one the load capacity than stiffeners on the plate.

## INTRODUCTION

Steel plate shear walls (SPSWs) are considered as one of the lateral resisting systems against wind and earthquake that transfer lateral loads through the tension field action to the boundary frame. Experiential and numerical researches—that have been conducted to investigate the behavior of different types of SPSW—indicated significant energy dissipation capacity and ductility as well as high load carrying capacity of this system [1-6]. Sabouri-Ghomi and Mamazizi [7], in an experimental investigation, evaluated effect of location of rectangular openings on the stiffness, shear capacity and energy absorption capacity of this system. Alavi and Nateghi [8] to investigate the seismic performance of diagonally stiffened SPSW with single-central circular opening have conducted an experimental study. They demonstrated that the diagonal stiffening is an appropriate strengthening method for the SPSW with a central opening. As introducing openings on the SPSW results in decreasing of the shear strength of SPSW and significant deformation of the infill plate, placement of stiffeners is around the openings and on the infill plate. Therefore, investigating the effect of stiffeners on the shear capacity of SPSW with rectangular opening is necessary. The aim of this paper is to investigate the effect of stiffeners on the shear capacity of the SPSW with rectangular opening by using nonlinear finite element (FE) method. For this issue, 45 specimens are modeled with and without stiffeners. In the investigated specimens, the variables parameters are thickness, yield strength, and opening area.

## SELECTED EXPERIMENTAL CASE AND FINITE ELEMENT SIMULATION

In order to validate the nonlinear FE model, the experimental investigation carried out by Sabouri-Ghomi and Mamazizi [7] is selected and simulated with ABAQUS. Sabouri-Ghomi and Mamazizi [7] tested a one-third scale specimen of one-story SSPSW with two rectangular openings. Fig.1 illustrates the details of the selected experimental specimen. Material properties of used steel in the experimental specimen are shown in Table 1. More details of the experimental test can be found in [7].

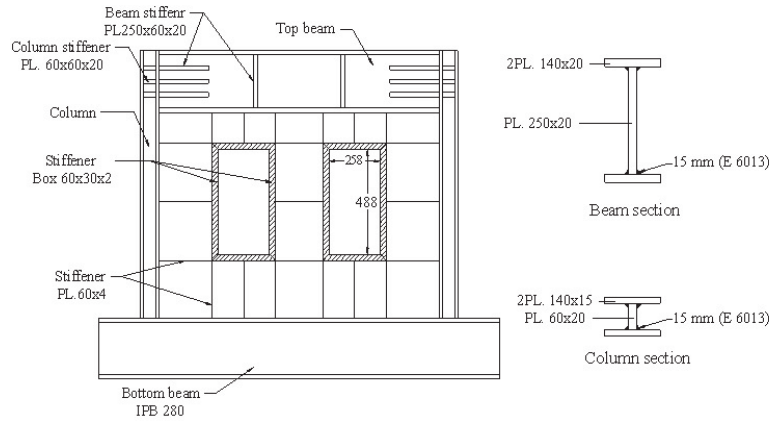


FIGURE 1. Details of selected experimental specimen for FE modeling with configuration of stiffeners; tested by Sabouri-Ghomi and Mamazizi [7].

TABLE 1. Material properties of used steel in the experimental specimen

Members	Plate thickness (mm)	Yielding stress (MPa)	Ultimate stress (MPa)	Modulus of elasticity (GPa)
Column	15	348.2	521.4	208
Top beam	20	415.7	557.2	209
Infill plate	2	189.5	299.9	206
Stiffeners	-	245.2	384.7	208

Comparison of nonlinear FE analysis and experimental test results are presented in Fig. 2. As shown in this figure, the results indicate appropriate agreement in terms of load-displacement behavior and stress distribution.

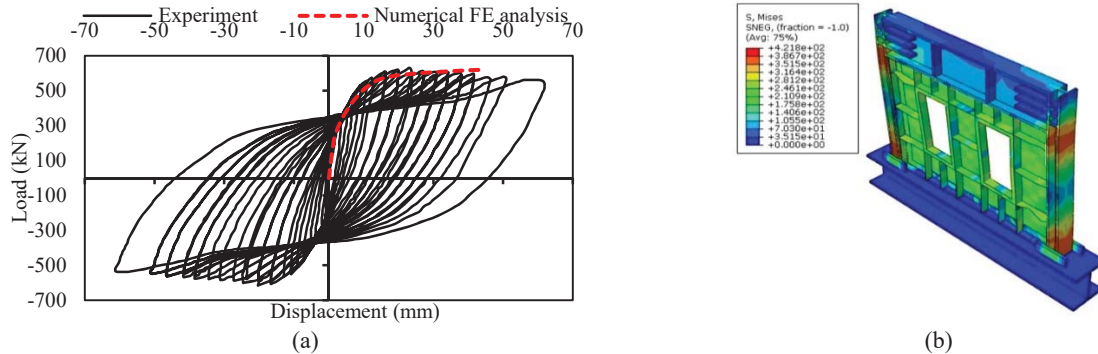


FIGURE 2. (a) Comparison of the results of experimental specimen with FE analyzing, (b) von Mises stress of FE model in ultimate displacement.

## PARAMETRIC STUDY

To investigate the effect of variation of effective parameters and stiffeners on the shear capacity of the SPSW with a rectangular opening, in total, 45 specimens have been modeled and analyzed. In the simulated models, variable parameters are thickness, yielding strength and opening area of SPSW. The models are named S-SPSW, NS-SPSW, and OS-SPSW that are representing the specimens with stiffeners, without stiffeners and stiffeners only around the openings, respectively, see Fig. 3. Response Surface Method (RSM) [7] is used to select the values of variable parameters for each specimen. Table 2 illustrates the characteristics of the simulated specimens with and without stiffeners with obtained FE analysis results. Fig. 4(a) shows the maximum load capacity of all simulated specimens. As shown, the elimination of all stiffeners causes of decreasing the maximum load by approximately 25% on average.



FIGURE 3. Mesh sizes of the FE models: (a) NS-SPSW without stiffener, (b) OS-SPSW with stiffeners around the openings.

TABLE 2. Characteristics of investigated specimen

Specimens	Yielding stress (MPa)	Thickness (mm)	Opening ratio (%)
1	150	2	35
2	200	2.5	20
3	150	2	25
4	200	3.5	30
5	200	2.5	40
6	250	3	35
7	150	3	25
8	250	2	35
9	300	2.5	30
10	250	2	25
11	150	3	35
12	200	1.5	30
13	250	3	25
14	200	2.5	30
15	100	2.5	30

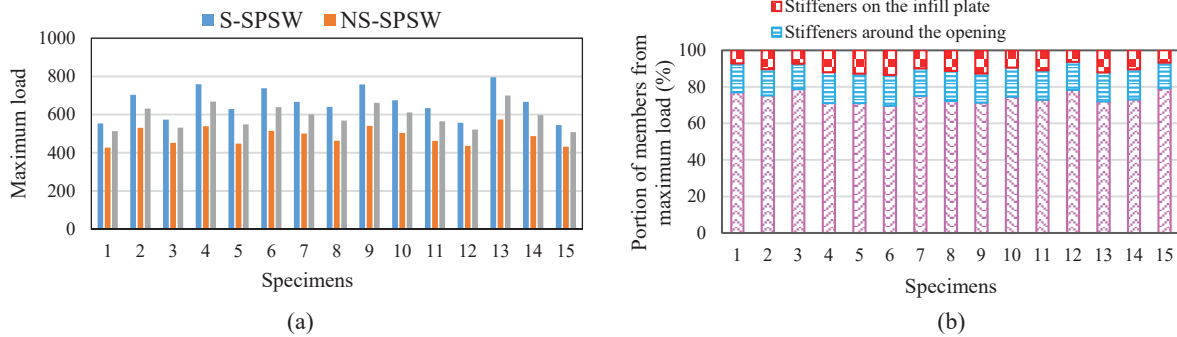


FIGURE 4. (a) Maximum shear load for all specimens, (b) absorbed portion of maximum load by the infill plate along with boundary frame, stiffeners around the openings and stiffeners on the infill plate.

Fig. 4(b) presents the absorbed portion of maximum load by the infill plate along with boundary frame, stiffeners around the openings and stiffeners on the infill plate; which are 74.16%, 15.66%, and 10.16%, respectively. As shown in this figure, absorbed portion by the stiffeners around the openings is greater than the one for the stiffeners on the infill plate. The main reason for this issue is using the stiffeners around openings might result in decreasing of large deformation, which avoids possible tearing of the infill plate on the edge of the rectangular openings. In Fig. 5, the maximum shear load in the specimens with thicknesses of 1.5, 2, 2.5, 3, and 3.5 mm are presented. In these specimens, yield strength of steel ( $F_y$ ) is equal to 200 MPa and the opening ratio is 30%. As shown in this figure, by increasing the thickness of infill plate greater reduction of maximum load is observed. As a result, increasing thickness of the infill plate causes to increase of the role of the stiffeners on the shear capacity of SPSW.

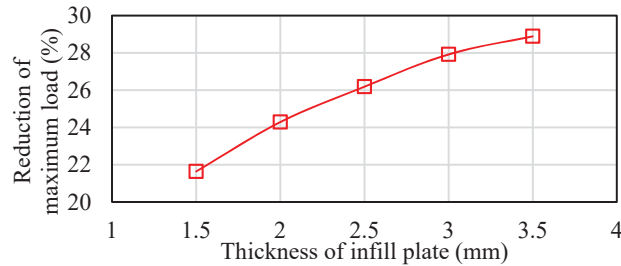


FIGURE 5. Maximum shear load in the specimens with different thicknesses of infill plate

## CONCLUSION

In this paper, nonlinear FE analysis is carried out to investigate the effect of stiffeners on the shear capacity of SPSW with a rectangular opening. For this issue, 45 specimens were modeled with/without opening and with stiffeners only around the opening. Variable parameters of the models are thickness, yielding strength and opening area of the infill plate. Summary of results are as follows:

- in the investigated models with rectangular openings, elimination of all stiffeners causes to decrease of maximum load approximately by 25%;
- the absorbed portion of maximum load by the infill plate along with boundary frame, stiffeners on the infill plate and stiffeners around the openings that are 75%, 10%, and 15%, respectively;
- stiffeners around the openings have more effect on the maximum shear load capacity of this system comparing with the stiffeners on the infill plate.
- increasing the thickness of infill plate develops effectiveness of adding stiffeners on shear capacity of SPSWs.

## FUTURE ACTIVITIES

This paper presents preliminary results of investigating the effect of stiffeners on the shear capacity of SPSW with rectangular openings; to this aim, specimens are modeled with/without stiffeners, and with stiffeners only around the openings. To achieve comprehensive conclusion, investigation on different percent of stiffeners in frames with different aspect ratio ( $L/h$ ,  $L$  is the length and  $h$  is the height of the infill plate) is essential. Eventually, evaluation of mentioned parameters on the ductility of the specimens can be considered as another target.

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